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DIURNAL VARIATIONS IN TRAFFIC FLOW AND CARBON MONOXIDE CONCENTRATIONS

by

Gerard A. DeMarrais
Meteorology and Assessment Division
Environmental Sciences Research Laboratory
Research Triangle Park, N.C. 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, N.C. 27711

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Mr. DeMarrais is a meteorologist in the Meteorology and Assessment Division, Environmental Sciences Research Laboratory, Environmental Research Center, Research Triangle Park, N.C. 27711. He is on assignment from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

ABSTRACT

Traffic count and carbon monoxide (CO) data for January and July from three states are compared in order to reveal any diurnal variations in the two measurements. The diurnal patterns for the 18 traffic count stations indicate that there are average patterns of traffic flow that are representative of all stations for periods of one month. Comparisons of data for the 36 CO monitoring stations show correlations which vary from large positive to large negative. However, eliminating a few monitoring stations which show relatively poor correlations yields groups within each state that have consistent patterns. The diurnal variations in CO concentrations are not well correlated with traffic patterns. Part of the poor correlation appears to be due to the diurnal variations in vertical mixing and wind speeds and part to the exposures and locations of the sampling instruments.

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1. INTRODUCTION

The major source of man-made carbon monoxide (CO) in the atmosphere is the automobile. In evaluating the CO air pollution problem, attempts have been made to correlate CO concentrations with traffic density (1-5). The findings of a short study (1) conducted in an unidentified city in the northeastern United States during the summer of 1959, and a year-long study (2) in 1964-1965 in Frankfurt/Main, Germany, found that the correlations between CO concentrations and traffic density were relatively high. A more recent study by the author (3) using data for 1973 from the Baltimore area showed correlations less than 0.50 between hourly CO concentrations and traffic counts. Since the results of this third study were inconsistent with those of the two earlier studies a large volume of CO concentration and traffic count data were sought. The objective was to determine the diurnal patterns of CO concentration and traffic at a number of sites and then compare the patterns. Meteorological phenomena are discussed only when they obviously caused an anomaly or when they did not appear to be the cause of a discrepancy. A better understanding of the combined effects of traffic and meteorology on CO concentrations is being sought in a separate study in which wind data from the individual monitoring sites, area mixing height data, CO concentrations from four Maryland sites, and local traffic counts are being analyzed.

To minimize the possibility of differences in CO concentrations being attributed to differences in sampling procedures or times, new data, which were collected in a standard manner, were sought for this study. Each state air pollution control agency is now required by Federal regulations (6) to continuously collect hourly CO data at stations within its boundary according to a standard procedure. Highway agencies throughout the United States also collect hourly traffic data at a number of permanent counting stations. In order to determine whether there might be differences in diurnal patterns of CO concentrations between states or possibly between regions, data from the air pollution control agencies and highway departments of the States of Colorado, Maryland, and New Jersey were obtained. The National Air Data Bank (NADB) of the U.S. Environmental Protection Agency, (EPA), which stores air pollution data gathered from throughout the United States, provided the carbon monoxide information for the three states considered in the study.

2. CONCLUSIONS

Traffic at 18 sites, which ranged from resorts in Colorado to the beltline in Baltimore, showed relatively consistent patterns in diurnal variations. By comparison, the diurnal variation in CO concentrations at 36 sites showed large differences and were not well-correlated with traffic patterns. Much of the poor agreement was due to: 1) diurnal variations in vertical mixing and wind speed and 2) the differences in the locations of the air sampling intakes with regard to sources (tail-pipes). The poor agreement due to intake locations will be eliminated when agencies comply with the U.S. Environmental Protection Agency guidelines (12) for siting CO instruments; more readily comparable CO data will then be available for correlating with traffic and meteorology.

3. METHODOLOGY

TRAFFIC COUNT DATA

The traffic data collection programs of Colorado, Maryland, and New Jersey differ slightly, although all three states use automatic counters at permanent stations. In Colorado, data are continuously collected for opposing lanes of traffic and the total count is listed for each hour. In Maryland, the traffic for each direction is recorded separately on Interstate highways, but only the total is recorded on other roads. In New Jersey, traffic is recorded for one direction at a time; every week or two the counters are moved from one side of the road to the other.

Hourly traffic counts for Colorado (7) were obtained for four urban stations in the Denver area, an urban station in Pueblo, and two stations in resort areas. Of the 39 available Maryland stations (8), the following were selected: two on major highways between Baltimore and Washington, two on the beltline around Baltimore, two near a small city, one at an ocean resort, and one at a mountain resort. The available New Jersey data (9) consisted of one station on a truck route in Jersey City, one on a highway in a resort city, and one on a road on the outskirts of a small city. A brief description of each station is given in Table 1.

CARBON MONOXIDE CONCENTRATIONS

The CO data collection programs of the three states are similar because all states are required to summarize the data in an identical format for submission to the NADB.

Hourly CO concentrations for Colorado were obtained for three stations in the downtown Denver area and three in areas that were 5 to 6 miles from downtown Denver. In Maryland, data were obtained for one site in Baltimore; four in Washington, DC, suburbs; four in Baltimore suburbs; and one in Cumberland in the northwest part of the state. New Jersey stations included: eight in the metropolitan New York area--Bayonne, Elizabeth (Broad St.), Elizabeth (Turnpike), Hackensack, Jersey City, Newark, Paterson, and Perth Amboy; three in coastal areas--Asbury, Atlantic City, and Toms River; two in the Philadelphia-Camden complex--Camden (N. 6th St.) and Camden (Copewood); one in Trenton; and six in smaller cities and towns throughout the state--Burlington, Camden (Ancora), Freehold, Paulsboro, Penns Grove, Phillipsburg, and Somerville. A brief description of each station is shown in Table 2. The intakes (third column of Table 2) for the sample air are located from 10 to 17 feet above the ground over a trailer or out over city streets at a majority of the stations.

The Colorado and Maryland networks are predominantly trailer-type operations, but most of the New Jersey data are collected by instruments exposed over city streets. The intakes of the New Jersey instruments

are generally much closer to the traffic, and the stations except Camden 3 (Ancora) are in metropolitan or urban areas. Another major difference in intake exposures is that a majority of the Maryland stations have metal boxes (approximately (1' x 1' x 2') covering the intakes (opening is toward the ground). Thus there may be large differences in concentrations patterns because: 1) New Jersey collects at sampling sites which for the most part are in confined street canyons very close to the traffic; 2) Colorado collects air samples over trailers parked in open lots some distance from traffic; and 3) Maryland uses trailers in open lots and restricts the free air flow, at most stations, with metal boxes.

TRAFFIC DENSITIES VERSUS CONCENTRATIONS

In each of the three states, no permanent counting station is closer than 2 miles to a CO monitoring station. Because high CO concentrations are localized phenomenon (10), data from individual traffic count sites and CO monitoring stations are not directly comparable. However, predominant statewide patterns of the diurnal variations of CO concentrations and traffic density can be compared.

ANALYSES OF DATA

The distribution of traffic count and CO monitoring stations provides for an analysis of spatial similarities and differences. For seasonal comparisons January and July data are examined. To indicate how the absolute values differed among the stations, the average daily traffic (ADT) for each counting station and the average hourly CO concentration in parts per million (ppm) for each monitoring station are shown in graphical presentations. Each hourly value is plotted as a point at the midpoint of the observation period. All the data were normalized before being graphically presented or analyzed; all hourly values were converted to percentage of the 24-hour total.

4. RESULTS

TRAFFIC COUNTS

The diurnal variations of traffic during January for the 18 counting stations are shown in Figure 1. A consistent feature of the distribution is the occurrence of a traffic peak late in the afternoon. In addition, two-thirds of the stations show pronounced morning peaks. All stations have marked increases in volume in the early morning, and a few show the increase persisting until the afternoon peak is attained. All stations also show a steep, generally steady decline in traffic density between the afternoon peak and midnight. All three of the mountain resort stations (C7, C39, M35) are single-peak stations, but both ocean resorts (M17, NJ208) show two marked peaks, similar to those found in the heavy traffic stations (C22, M31, M32) in metropolitan areas. Only 30 to 40 percent of the total 24-hour traffic is counted before noon at all of the stations. The ADT ranges from 1,137 at a mountain resort in Colorado (C39) to 94,818 in downtown Denver (C22).

In July, (Figure 2), all stations except one (M25) experience greater ADT than they do in January (see Figure 1). The average increase in volume from January to July at the 13 nonresort stations in 19 percent; whereas, at the five resort stations it is 200 percent. The ADT during July for all stations ranges from 5,796 to 115,812. Although features of the January distribution reoccur in July, they appear in a modified form. The peak hourly flow still occurs in the afternoon at all stations except M17 but is not as marked as in January. At most stations, the morning peak is also lower. The sharp increase in traffic in the morning and the steep decline during the evening (6 PM to 9 PM) are almost as prominent as they were in January. At all of the resort stations except NJ208, the traffic count is high from late in the morning until 4 to 5 PM. Overall, the general traffic patterns at the 13 nonresort sites do not vary much between January and July.

To examine the interrelationships among the traffic count distributions, the data in Figures 1 and 2 were statistically analyzed. The bivariate correlation analyses of the January data showed that 75 percent of the paired stations were correlated at the 0.90 level or greater. Correlations that were less than 0.90 are shown in Table 3. The lower valued correlations are associated with the New Jersey sites and the resort stations. Even the poorest correlation (0.78 between NJ409 and C39) means that more than 60 percent of the variance at the resort in Colorado can be explained by the variations at a suburban site in New Jersey. It is concluded, therefore, that traffic patterns are similar among these 18 diverse stations. The bivariate analyses of the July data showed that 80 percent of the correlations were 0.90 or greater. Table 4 shows the correlations that were less than 0.90. The lower-valued correlations generally occur where heavy urban traffic is compared with resort traffic

and with the suburban traffic of the small New Jersey city. The poorest correlation in July (0.76) occurs between the mountain resort in Maryland and an interstate highway location in Denver. In this case, 58 percent of the variance at one place is explained by the variation at the other. Again, traffic patterns appear fairly consistent among the 18 stations. The seasonal variations at the individual stations were checked by comparing the diurnal variations of January and July. The results are shown in Table 5. The poorest correlation is 0.87 and a majority of the correlations are 0.97 or more. Thus, winter and summer patterns are very similar for these stations.

Because the statistical results indicate that the monthly average daily traffic pattern varies little from station to station, the data for the 18 stations were combined. The composite traffic patterns for January and July, including standard deviations, are quite similar (see Figure 3). The standard deviations indicate that the greatest spatial variations occur around the time of the morning peak traffic flow in both months and the afternoon peak flow in January.

CO CONCENTRATIONS

The results of the CO analyses showed more intrastate than interstate consistency. The results for each state, therefore, are considered separately.

The January diurnal variations of CO concentrations for the six stations in Colorado (Figure 4) show a fairly consistent pattern. There are two peaks in concentrations that approximately coincide with times of peak traffic flow (see Figure 3). The average hourly concentrations, shown in parentheses in the figure, range from 3.1 to 7.8 ppm. The morning peak in concentrations is as high or higher than the afternoon peak at all stations. At half of the stations, the midday concentrations and the lowest nighttime concentrations are very similar. This phenomenon of concentrations being the same at night and midday was common (it occurred at Maryland and New Jersey stations) and is attributed to the diluting capacity (vertical mixing and wind speed) of the atmosphere. Vertical mixing spreads emissions through a surface-based layer which varies in depth from a minimum during the nighttime hours to a maximum in late afternoon or evening and wind speed transports and spreads emissions downwind and is also at a minimum at night and maximum in the afternoon or evening. During midday the diluting capacity is near the maximum so the concentrations are reduced to low values. There are seasonal and spatial differences in these mixing height and wind speed patterns (11) but the timing of the maximum and minimum dilution change only a little. The cross-relation analyses of station data show that the Welby station is the least correlated with other stations (Table 6). Excluding Welby, all the correlations are 0.61 or better. (By comparison, the poorest correlation in January among the seven traffic counting stations in Colorado was 0.85.)

The July diurnal variations of CO concentrations for the Colorado stations, (Figure 5) show no consistent pattern. The average hourly concentrations, except at Colfax, are at most half of the January levels, ranging from 1.1 to 3.9 ppm. Although there is a peak in concentration

at 6 to 7 AM at five of the six stations, the afternoon concentration peak corresponding to the peak traffic hours is seen at only three stations. The morning peaks in July are displaced to slightly earlier times than those of January (Note that these CO concentrations are plotted at standard times and in July daylight times were observed). At five stations, marked peaks occur between 8 and 11 PM. These time delayed peaks in concentrations in July were common (they occurred at Maryland and New Jersey stations) and are attributed to meteorological causes; the principal causes of dilution, vertical mixing and wind speed, are at their maximums (11) at the time of peak traffic flow and do not subside until evening. At Julian, the concentration is considerably lower in the middle of the day than it is at night, but the reverse is true at Arvada, Broadway, Colfax, and Huron. The correlations for July (see Table 7) show that the distributions are much less correlated than they were in January, with most correlations less than 0.60 and many of these negative. Since the traffic patterns are fairly consistent (Table 4) one might suspect that variations in meteorology (mainly vertical mixing and wind speed) might cause these relatively poor correlations. However it is difficult to believe that differences in the meteorology in such a small area (all of the Colorado stations are within six miles of downtown Denver) could be large enough to account for inconsistent correlations.

In January diurnal variations in CO concentrations for the 10 stations in Maryland (Figure 6) are very similar to the January variations in Colorado. There are two peaks in concentrations that approximately coincide with the peaks in traffic flow. The average hourly concentrations, which range from 0.9 to 3.7 ppm, are considerably less than those for Colorado. At all but one of the sampling sites, the morning peaks are markedly higher than the afternoon peaks and the lowest daytime concentrations are very similar to those at night. As shown in the figure, the distributions at Riviera Beach are obviously inconsistent with those from the remaining nine stations and, therefore, are not included in the summary statements that follow. Results of the regression analyses of these January data (Table 8) show that the variations for Riviera Beach are very poorly correlated with the variations for the other stations. In general, the correlations among the other nine stations are high and comparable to the January correlations found in Colorado.

The July variations in CO concentrations for the Maryland stations (Figure 7) show a fairly consistent pattern when the results from Riviera Beach are not considered. The average hourly concentrations, which range from 0.5 to 2.9 ppm, are generally slightly lower than they were in January. The morning peaks are displaced to earlier times (the morning rush hour is earlier because of daylight saving time) and are smaller than they were in January. The afternoon peaks are displaced to much later times, generally 8 to 10 PM; there is very little indication of a peak in CO concentrations occurring at the time of peak traffic flow. At seven of the nine stations, the afternoon peak concentrations are higher than the morning peak concentrations; during January the peaks were higher in the morning. At a majority of the stations, the midday concentrations are lower than the lowest concentrations that occur

at night. The bivariate analyses of the July data (Table 9) show similar results to those for January. Riviera Beach data are, again, very poorly correlated. The correlations among the other nine stations are comparable to those for January at the Maryland stations but are generally greater than the correlations shown in July in Colorado.

The January diurnal variations in CO concentrations for the 20 stations in New Jersey (Figure 8) are not similar to the January variations for Colorado and Maryland. Close inspection indicates that increases in concentration do occur at the times of peak traffic volumes at most stations. These January peaks are not as pronounced as those for Colorado and Maryland, however. The average concentrations range from 1.0 to 8.7 ppm and span the relatively high values of Colorado and low values of Maryland. The Maryland data for January consistently showed that the highest concentrations occurred during the morning peak traffic flow; whereas, this phenomenon occurs at only six stations in New Jersey. Again in contrast to the Maryland data, the New Jersey data do not show similar values in the middle of the day and the early morning. The regression analyses demonstrate that about two-thirds of the stations correlate reasonably well (all pairings were 0.72 or greater. Table 10 lists the stations showing correlations of 0.72 or greater while Table 11 lists the 5 stations (in the vertical) and values associated with poorer correlations (in Figure 8 the stations showing correlations of 0.72 or greater are marked with an asterisk and the poorer with two asterisks). Note that four of the five stations showing poorer correlations also show relatively low average hourly concentrations.

The variations of CO concentrations for the New Jersey stations (Figure 9) show less consistency in July than in January and are thus similar to the Colorado and Maryland data. The values of average hourly concentration range from 1.3 to 7.3 ppm, a slightly lower average concentration than in January. It is interesting that 10 stations show increases and 10 show decreases in average hourly concentration from January to July. Features that do stand out in the July diurnal variations are: 1) at a majority of the stations, there is an increase in early morning concentrations that appears associated with the morning peak traffic flow; 2) at seven stations, the lowest concentrations occur in the middle of the day; 3) no increase in concentration occurs at the time of increased traffic (4 to 5 PM standard time); and 4) at a majority of stations, as with the stations in Colorado and Maryland, there are late evening (7 to 10 PM) peaks in concentrations. The July statistics for the stations that showed good and poor correlations in January are shown in Tables 12 and 13, respectively. It is obvious that the correlations from January to July decrease markedly. A sixth station, Camden 3, is added to the poorly correlated group because it showed correlations ranging from 0.69 to -0.72.

Five of these New Jersey stations, Bayonne, Elizabeth 1 and 2, Jersey City, and Newark, are in a five mile square area and three show well correlated data with other stations while two show poorer correlations. Again it is difficult to believe that meteorological variations from place to place would be great enough to cause these large differences in the small area.

INTERMONTH CORRELATION OF CO CONCENTRATIONS

Because the bivariate analyses showed that the correlations between stations decreased from January to July, a month-to-month comparison was made at each station. The resulting comparisons, Table 14, show:

1. No correlations better than 0.70 among the Maryland stations
2. Correlations that range from 0.55 to 0.86 at the Colorado sites
3. Correlations that range from -0.26 to 0.94 in New Jersey

COMPARISONS OF TRAFFIC AND CO CONCENTRATIONS

The composite distribution for the six CO monitoring stations in Colorado for January and July are presented in Figure 10. The vertical line at the middle of the hour shows the range of one standard deviation. The January data show a smooth two-peak distribution with the peaks appearing to coincide or follow within 1 hour of the peak in traffic flow (see Figure 3). The morning peak CO concentration is 50 percent greater than the afternoon peak concentration although the traffic data show the afternoon peak to be half again as great as the morning peak. The lower concentrations with the greater traffic flow (greater emissions) is attributed to the meteorology; in the morning, vertical mixing and wind speed, the causes of dilutions, are at their minimums and in the afternoon at their maximums. The standard deviations are relatively small during the night and early morning hours, indicating that there is generally little spatial variation from this CO pattern. The daytime standard deviations are moderate, indicating there is a fair amount of spatial variation from the composite pattern. The July pattern is not as smooth as that for January, but the CO peak associated with the heavy morning traffic is again evident. A slight peak occurs in the afternoon just before the time of peak traffic flow; a dip in concentration levels is then evident just before the primary evening peak concentration occurs at between 8 and 9 PM (9 to 10 PM daylight time). The standard deviations are relatively large, indicating considerable spatial variation from the average July pattern.

The composite results for the nine selected CO monitoring stations in Maryland (Riviera Beach data are not included in the average) for January and July are seen in Figure 11. These January data show a smooth two-peak distribution similar to those for Colorado. Each CO peak coincides or follows within 1 hour of the peak in traffic density. The morning CO concentration peak is 50 percent larger than the afternoon peak; the direct opposite is true of the comparable traffic peaks. Unlike the Colorado results, the Maryland data show concentrations as low during the day as they are at night. The standard deviations indicate that there is a large amount of spatial variation at the time of the morning peak and a fair amount at other times. The July pattern, like the January pattern, has two peaks. The morning peak, however, occurs earlier and is diminished in size, and the evening peak occurs later and is greater. Compared to the July CO pattern for Colorado, the Maryland pattern is more systematic. Like the Colorado results, the peak afternoon CO concentration occurs several hours after the peak in traffic flow. In addition, at the time of the peak traffic, no

marked increase in CO concentration occurs. In the middle of the day, concentrations are very similar to the lowest nighttime values. The standard deviations are large after 7 PM, indicating that there is a considerable amount of spatial variation in the evening.

The composite results for the 15 selected CO monitoring stations in New Jersey (the five stations with poor correlations are not included) are seen in Figure 12. Like the Colorado and Maryland data for January, the New Jersey data show a smooth two-peak distribution, although the peaks are less pronounced. The peaks do coincide with the peaks in traffic flow, however. Unlike the Maryland data, the New Jersey data show the daytime concentrations remaining high after the morning peak and always being about 2.5 times as great as the lowest morning values. The afternoon peak is higher in New Jersey; the morning peak was higher in Colorado and Maryland. The small standard deviations indicate that the spatial variations are relatively small, however. The July data, like those for Colorado and Maryland, show a less systemized variation than the January data. These July data show three slight peaks: one with the morning peak traffic; the second about the time of the afternoon peak traffic; and the final several hours after the peak traffic flow. The second and third peaks are similar to the July afternoon peaks in Colorado. The standard deviations are larger in July than in January, indicating that the July pattern shows larger spatial variations.

The numerical correlations of the statewide variations of CO concentrations with the traffic pattern averaged for the 18 counting stations vary over a large range (see Table 15). In January, the poorest correlation, 0.25, is associated with the Maryland CO data and the best, 0.94, with the New Jersey data. The indication is that traffic variations explain only 6 percent of the CO variation in Maryland, 27 percent in Colorado, and 88 percent in New Jersey. In July, the correlation between traffic and Colorado Co variations increases, but in the other two cases it decreases. The Maryland data, in fact, even show a negative correlation. The interstate CO comparisons in Table 15 show wide variations in correlations in both January and July. In January, the correlation between Maryland and New Jersey data is only 0.42, and in July it decreases to 0.31. In July, the variation in one state can be used to explain less than 10 percent of the variation in the other. With the states being so close to one another, a better correlation was anticipated. The interesting phenomena in the Colorado-Maryland and Colorado-New Jersey correlations is the exchange of absolute values from January to July. It is strange that the variations in CO in Colorado can be used to explain 72 percent of the variation in Maryland in January and only 43 percent in July; for New Jersey the Colorado concentrations explain 41 percent in January and better than 75 percent in July.

5. SUMMARY

The results of the study are summarized in the following paragraphs:

The hourly variations of ADT at 18 permanent counting stations located in various types of areas in three states during January and July showed considerable spatial and temporal consistency even though the ADT counts ranged from 1,000 to 100,000 venicles. For periods of a month, there are average patterns of diurnal variation of traffic flow that are representative of all stations.

The diurnal variations of CO concentrations for 36 monitoring stations, located for the most part in urban areas or near well-traveled roads in the three states, showed correlations that varied from large positive to large negative when one-to-one comparisons were made.

Although comparisons of data from all 36 monitoring stations showed correlations varying over a large range, intrastate comparisons showed smaller ranges in July and much smaller ranges in January. Eliminating stations that showed poor correlations yielded groups within each state that showed consistent patterns.

The Maryland stations generally showed lower average hourly concentrations than the Colorado and New Jersey CO monitoring stations. The Maryland stations have metal boxes over their intakes that may account for the differences with the Colorado stations. The New Jersey stations are generally closer to the traffic than the Maryland stations--a fact that may account for the higher observed values. Before attempting to correlate traffic and meteorology with CO concentrations in various states, it would be desirable to have the siting of instruments standarized. The U.S. Environmental Protection Agency has published guidelines (12) for siting instruments and with time state and local agencies may comply with these guidelines and provide comparable data.

The relatively high CO concentrations that occur late in the day in July were an unexpected anomaly. Because they occurred in so many places, there is little doubt that they are real. This time delay in peak concentration is attributed to the diurnal variations in vertical mixing and wind speed. These pheonmena provide for maximum dilution at the time of peak traffic flow and at later times, when the speeds and mixing heights are much lower, concentrations increase.

The comparison of the January versus July CO variations at the individual stations showed: 1) poor correlations in Maryland (all less than 0.70); 2) correlations in Colorado ranging from 0.55 to 0.86; and 3) correlations ranging from -0.26 to 0.94 in New Jersey. These correlations are much more erratic than the comparable traffic correlations, which ranged upward from 0.87 with a majority being greater than 0.96. It appears there is a significant seasonal change in CO concentrations.

In comparing the January diurnal variations of CO concentrations and traffic volume, there was an obvious correlation of the timing of the diurnal peaks of each. There was not a good one-to-one correlation between concentrations and traffic density, however, because the traffic pattern showed an afternoon peak that was twice as great as the morning peak. In addition, Colorado and Maryland concentration patterns showed peaks in the afternoon that were half as great as those in the morning. The diurnal variations in vertical mixing and wind speed partially account for this apparent anamoly. These phenomena allow for minimum dilution of emissions with peak morning traffic and maximum dilution with peak afternoon traffic.

In Maryland in January and July and at three stations in Colorado in January and seven stations in New Jersey in July, the midday concentrations were consistently as low as the lowest nighttime values. There was almost an order of magnitude difference in traffic volume at the two different times. Traffic density and concentration were very poorly correlated at these stations and times. The diurnal variation of meteorological parameters are the cause of this discrepancy. Emissions are diluted very little at night because vertical mixing and wind speed are at their minimums and around midday emissions are readily spread through much larger volumes as vertical mixing and wind speed are approaching maximums.

Even when the CO data were compiled into average diurnal variations for each state, the correlations between traffic and CO concentrations were still erratic; in Colorado in January, 27 percent of the variation in CO concentrations was explained by the traffic and in July 33 percent; in Maryland the correlation was 0.25 in January and -0.19 in July; in New Jersey 88 percent of the variation in CO concentrations was explained by the traffic in January and 62 percent in July.

The results of this study are inconsistent with those studies (1,2) that found high correlations between CO concentrations and traffic. The instruments used in this study were modern, were checked for accuracy, and were in locations comparable to those used in the other studies (about 30 to 50 feet from traffic in the northeastern city [1] and about 2 to 3 meters from the building walls in Frankfurt/Main [2]). This study indicates that the diurnal variations of traffic are spatially and seasonally consistent but that the diurnal variations of CO concentrations are inconsistent. There are times and places, however, at which there may be a high correlation between the variations of the parameters. This appears to have been the situation in the northeastern city and in Frankfurt/Main in the earlier studies.

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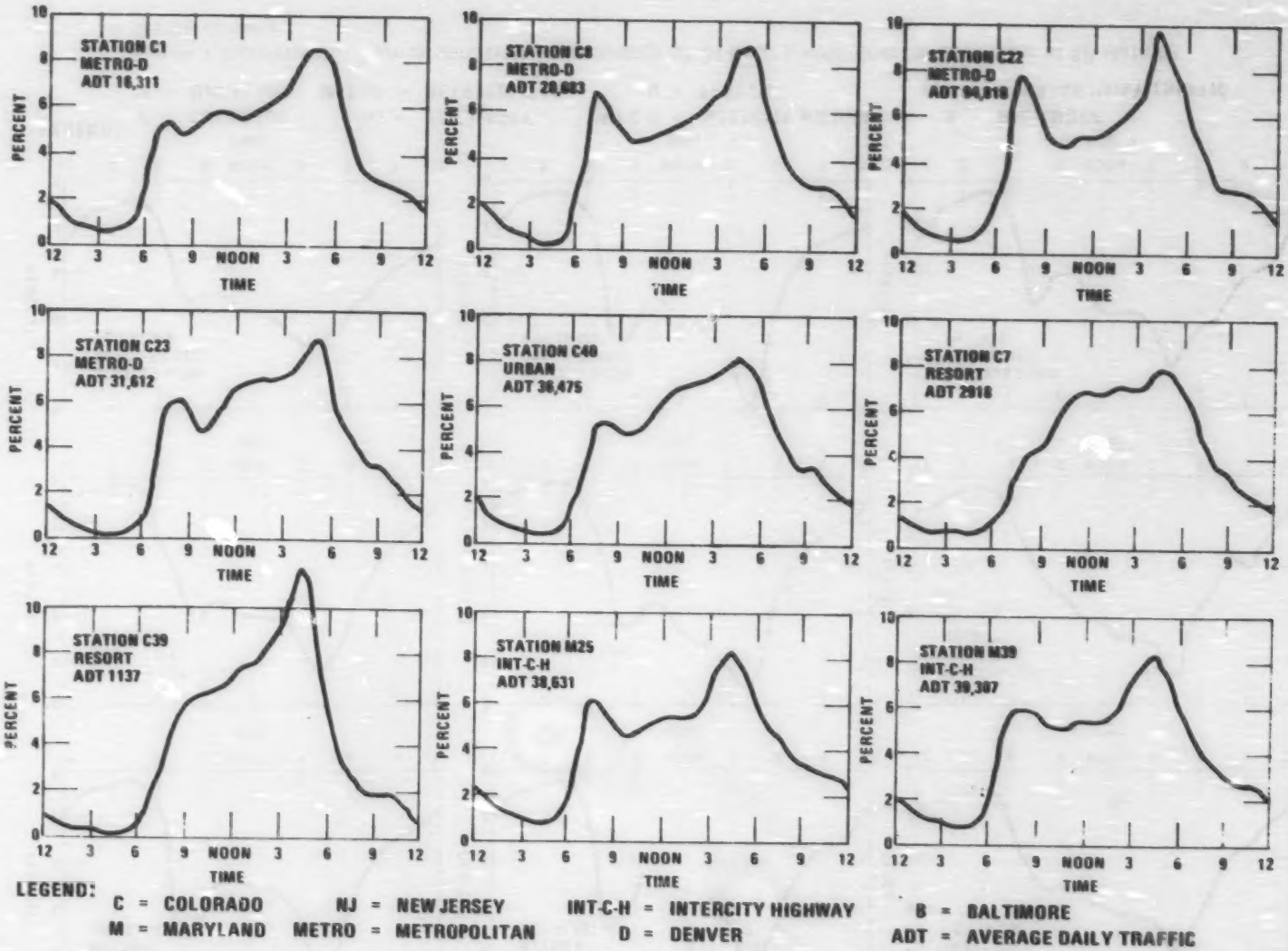

Figure 1. Diurnal variation in percentage of 24-hour traffic flow for each hour at 18 stations during January.

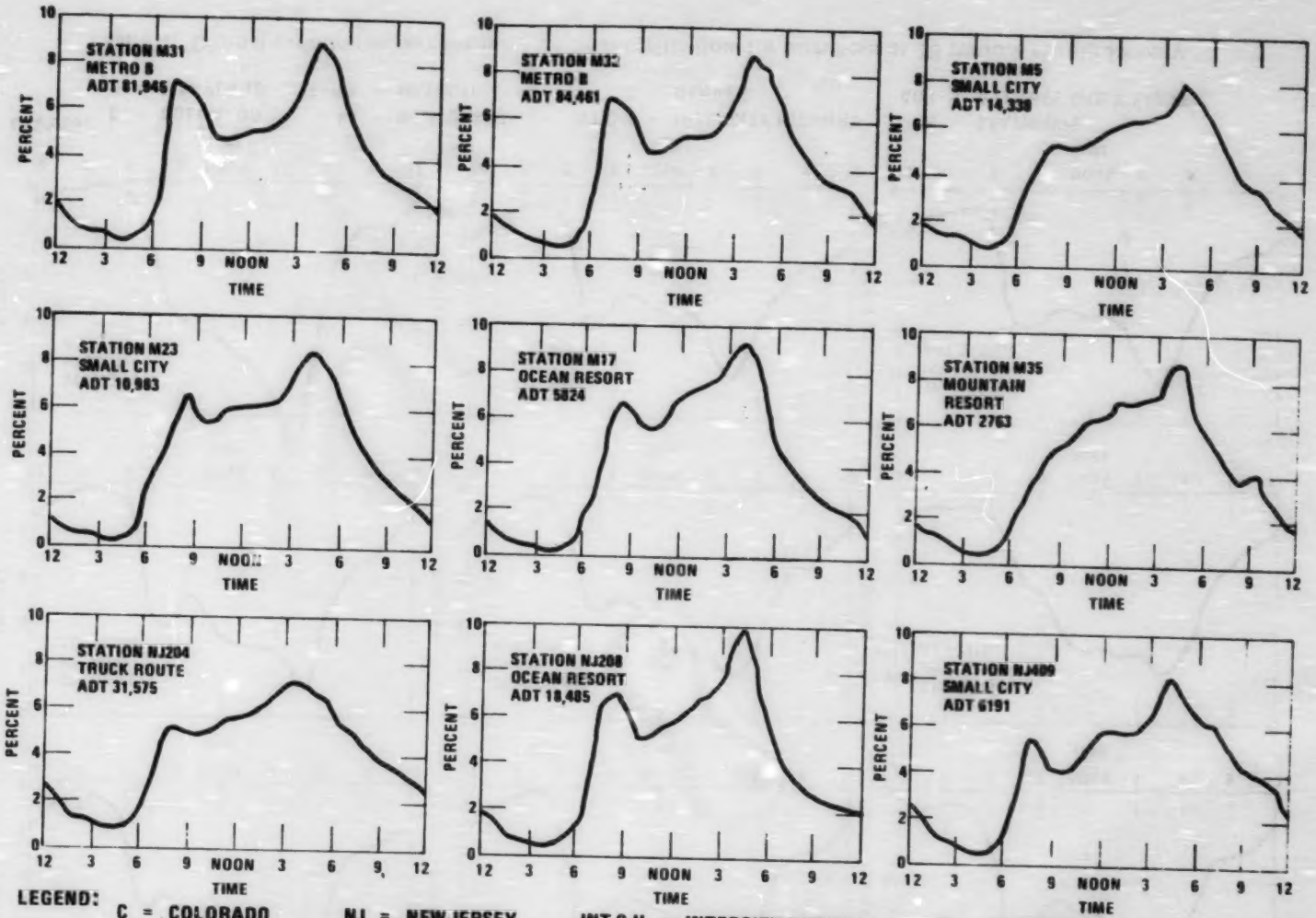

Figure 1 (continued). Diurnal variation in percentage of 24-hour traffic flow for each hour at 18 stations during January.

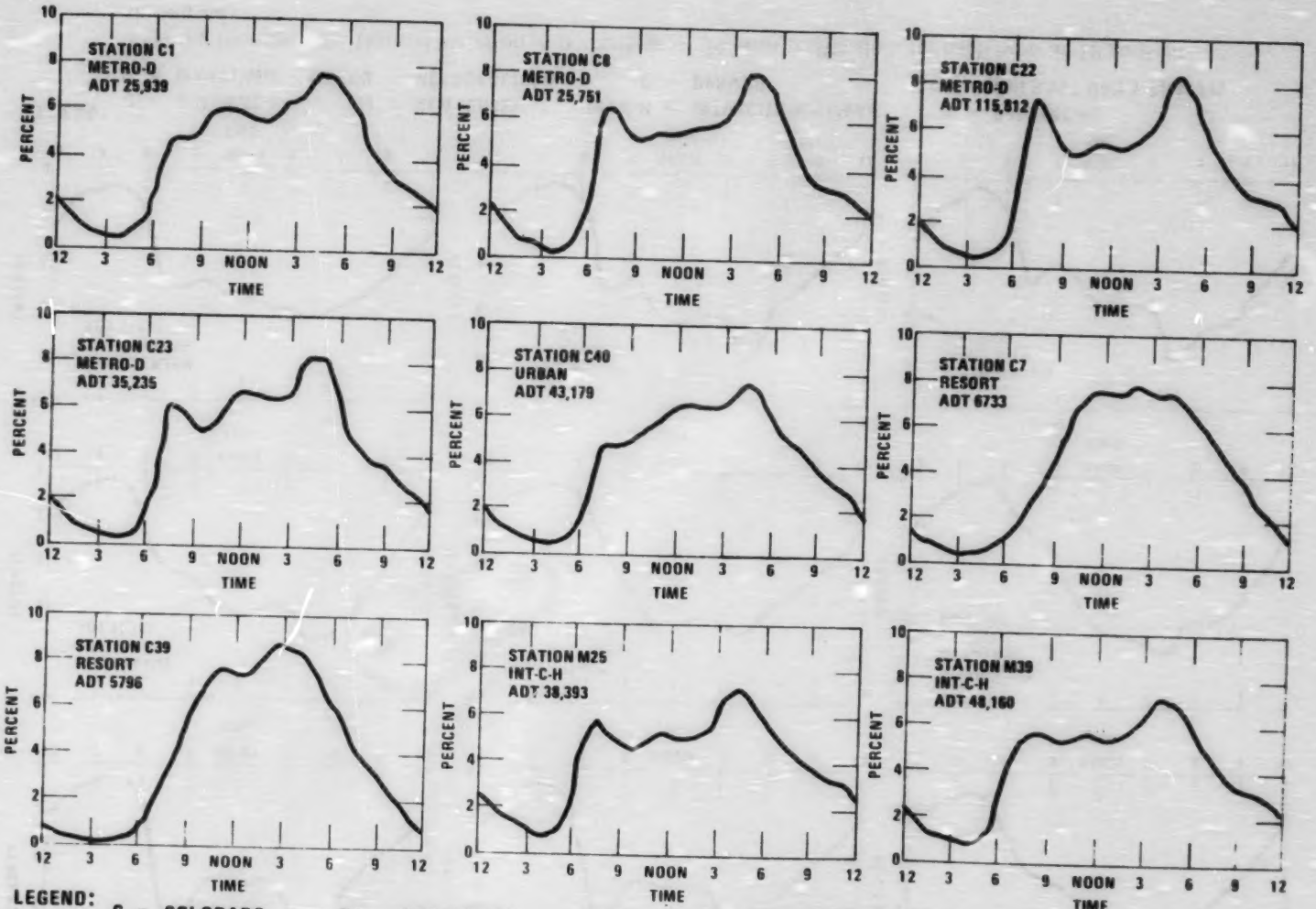

Figure 2. Diurnal variation in percentage of 24-hour traffic flow for each hour at 18 stations during July.

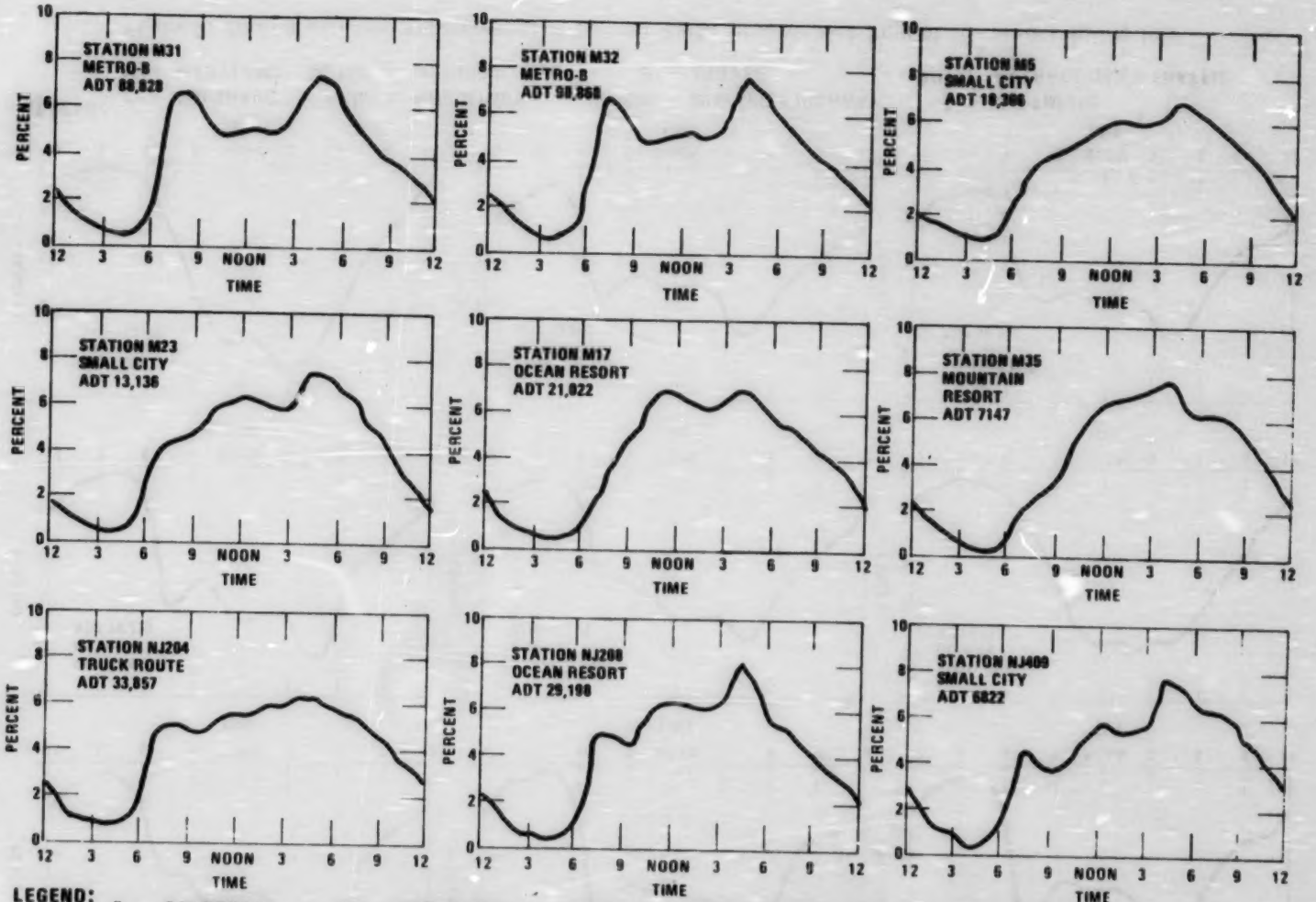

Figure 2 (continued). Diurnal variation in percentage of 24-hour traffic flow for each hour at 18 stations during July.

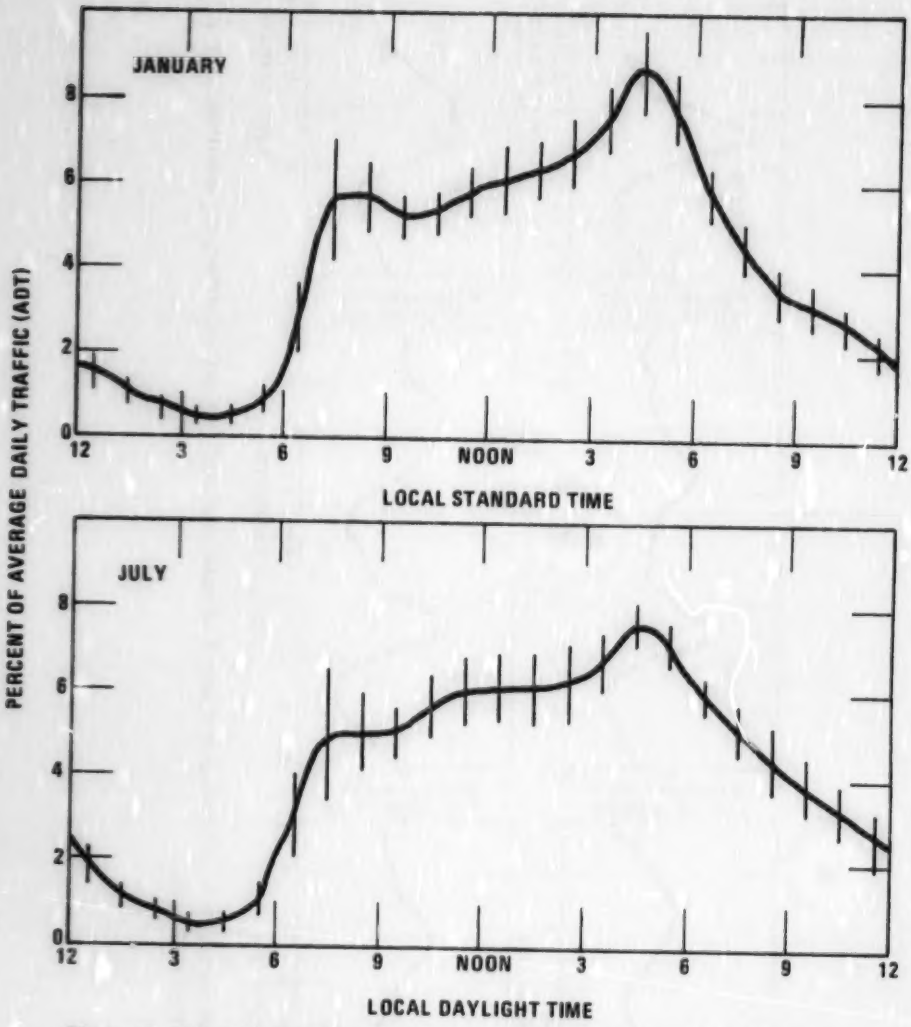

Figure 3. Diurnal variation in average traffic, 18 stations (vertical lines show ranges of ± 1 standard deviation).

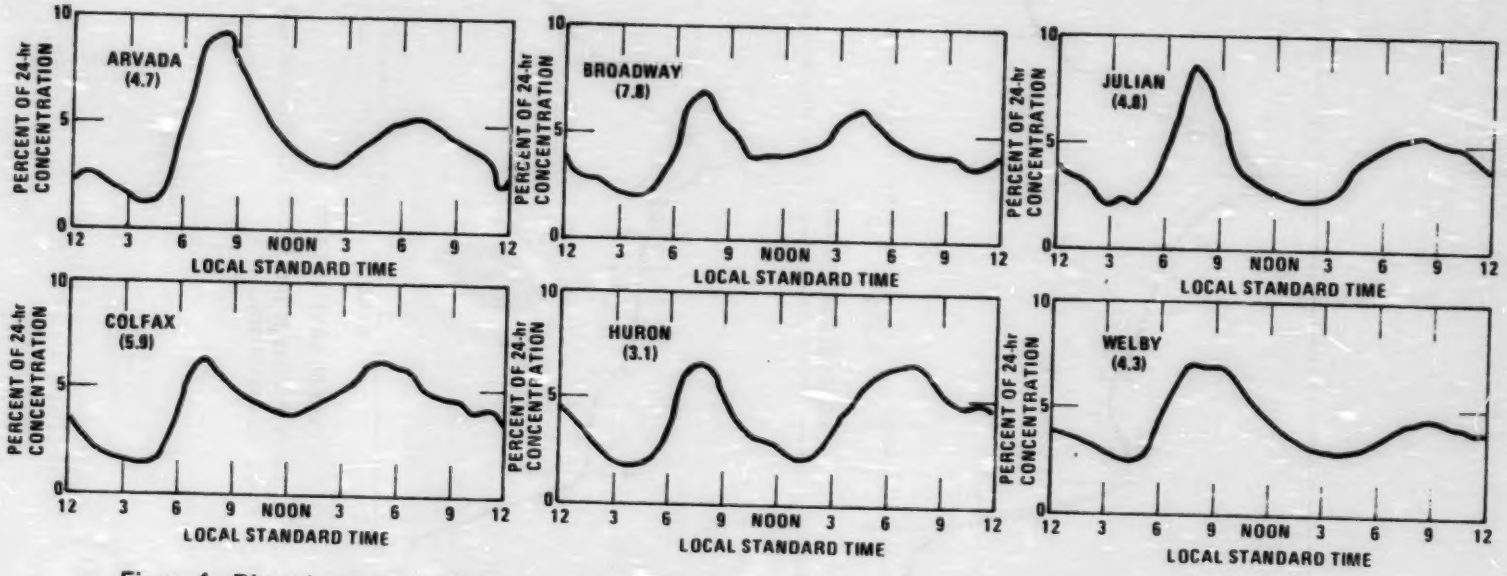

Figure 4. Diurnal variation in CO concentrations, Colorado stations, January (numbers in parentheses are average hourly concentrations in ppm).

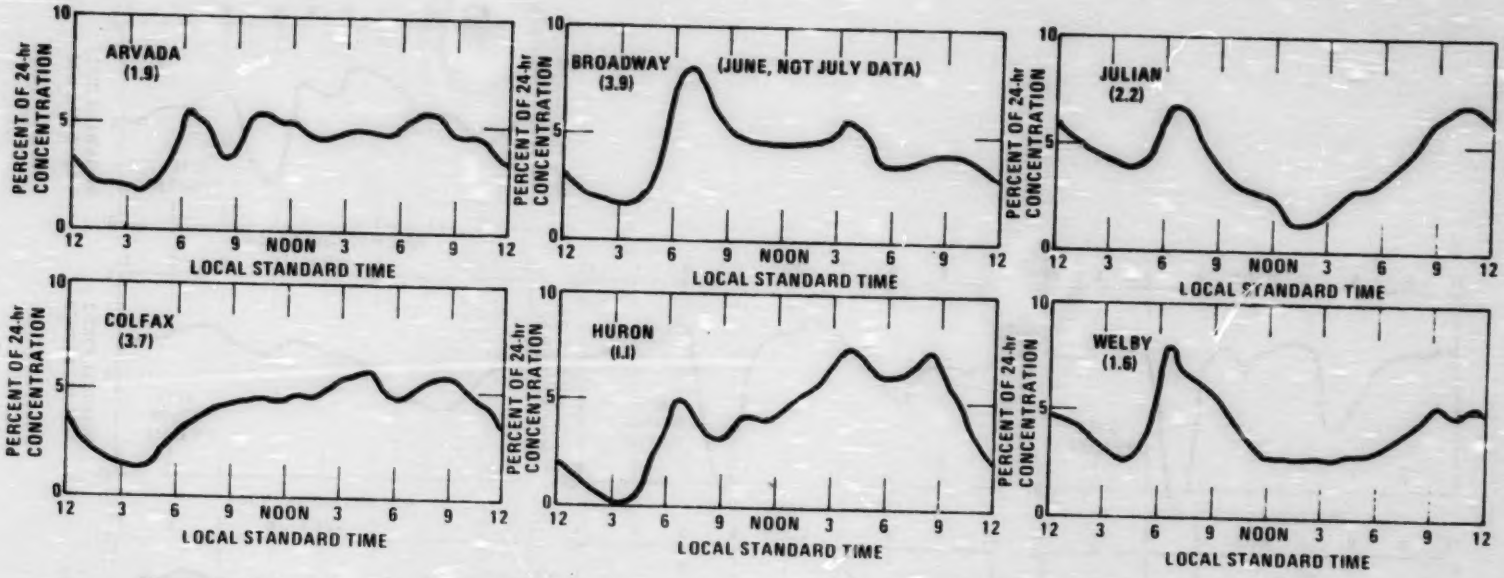

Figure 5. Diurnal variations in CO concentrations, Colorado stations, July (numbers in parentheses are average hourly concentrations in ppm).

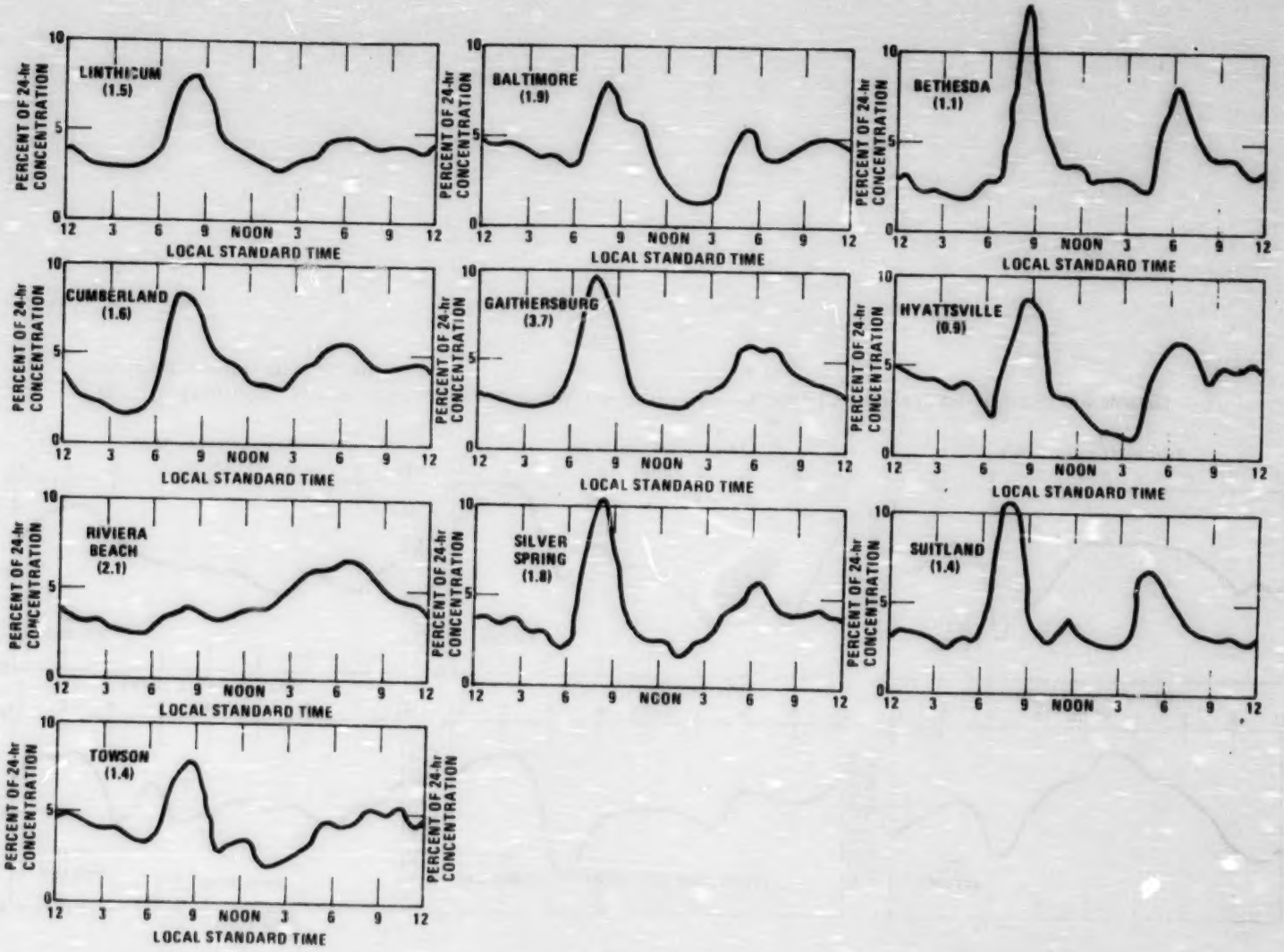

Figure 6. Diurnal variations in CO concentrations, Maryland stations, January (numbers in parentheses are average hourly concentrations in ppm).

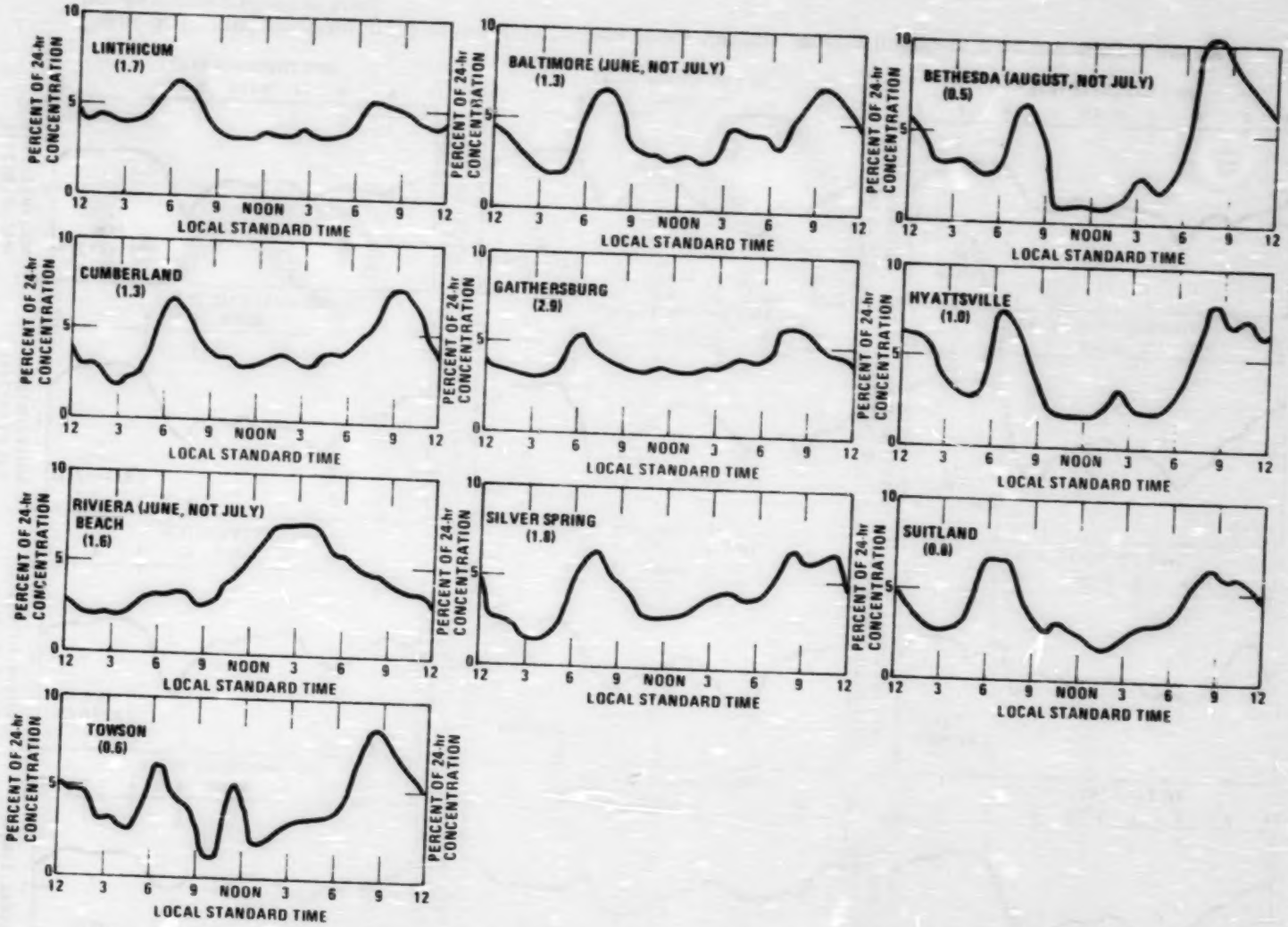

Figure 7. Diurnal variations in CO concentrations, Maryland stations, July (numbers in parentheses are average hourly concentrations in ppm).

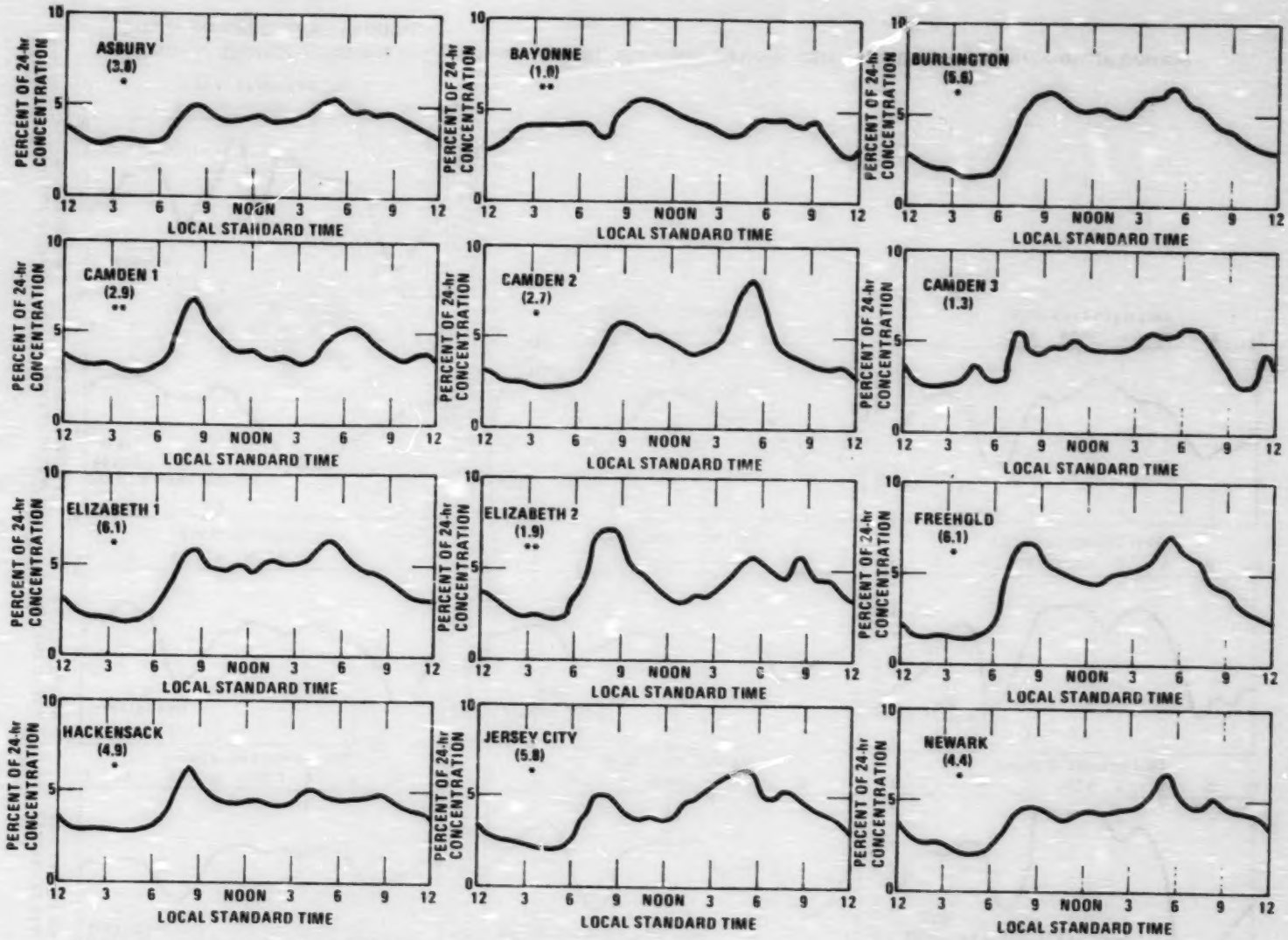

Figure 8. Diurnal variations in CO concentrations, New Jersey stations, January (numbers in parentheses are average hourly concentrations in ppm).

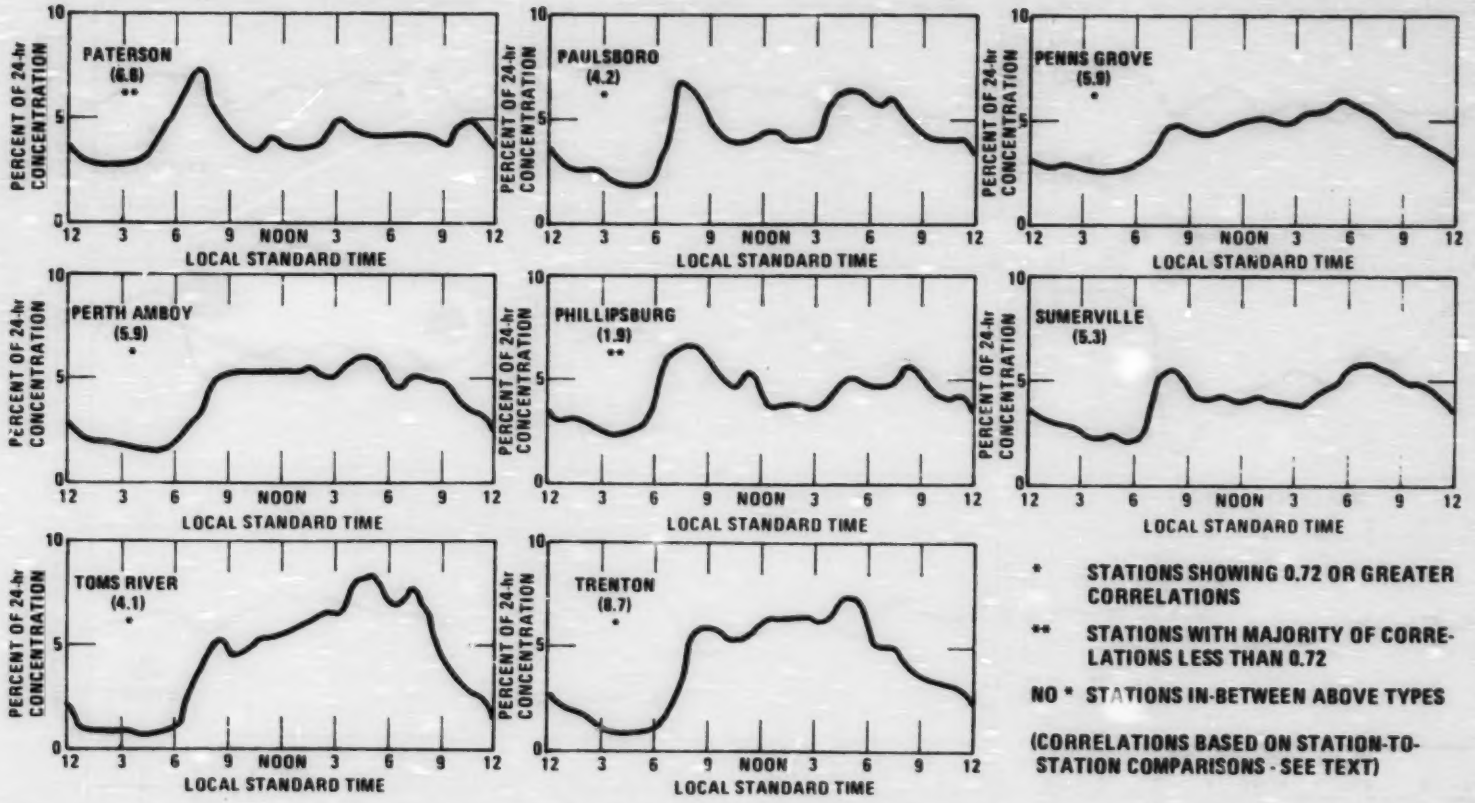

Figure 8 (continued). Diurnal variations in CO concentrations, New Jersey stations, January (numbers in parentheses are average hourly concentrations in ppm).

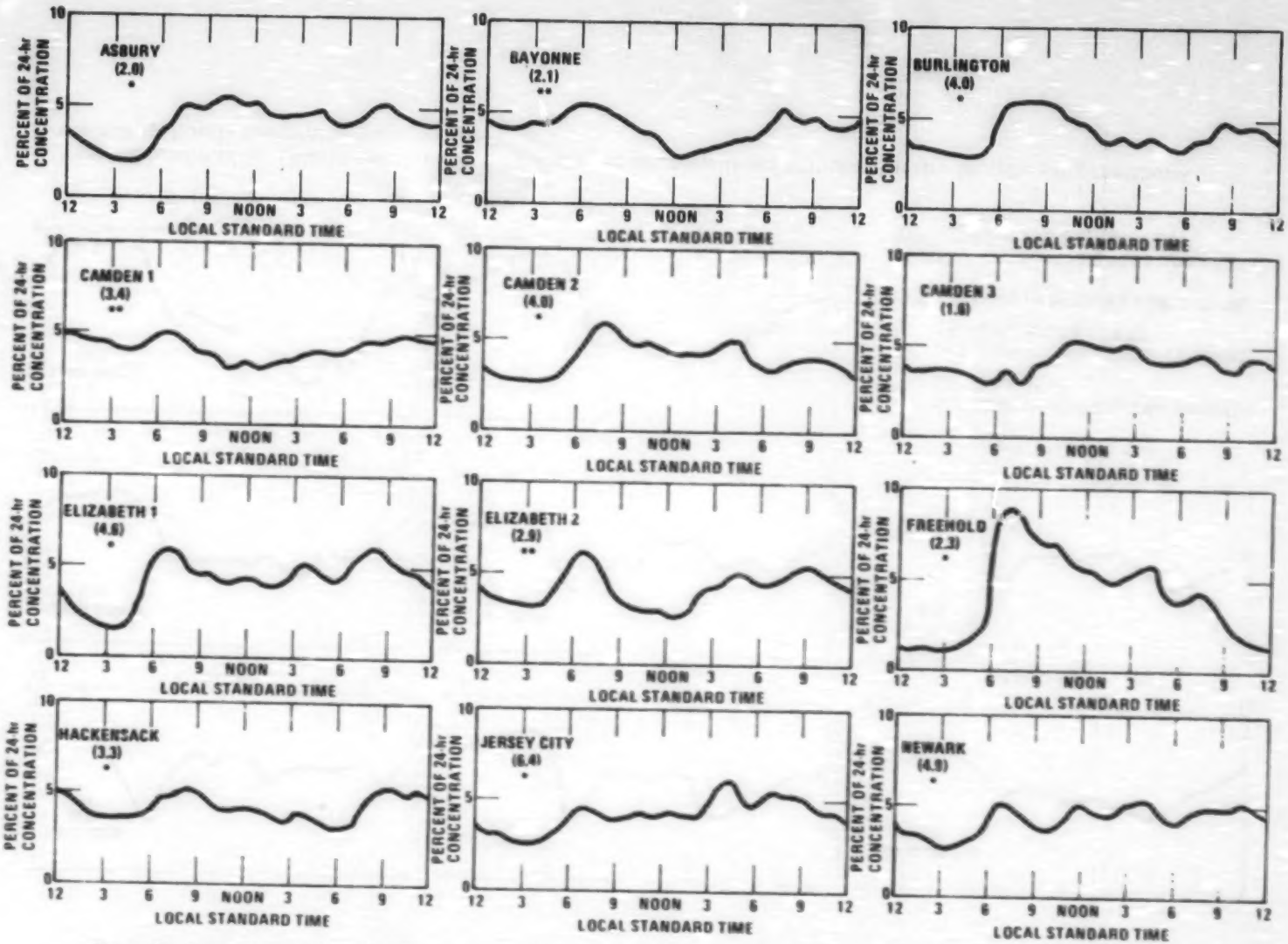

Figure 9. Diurnal variations in CO concentrations, New Jersey stations, July (numbers in parentheses are average hourly concentrations in ppm).

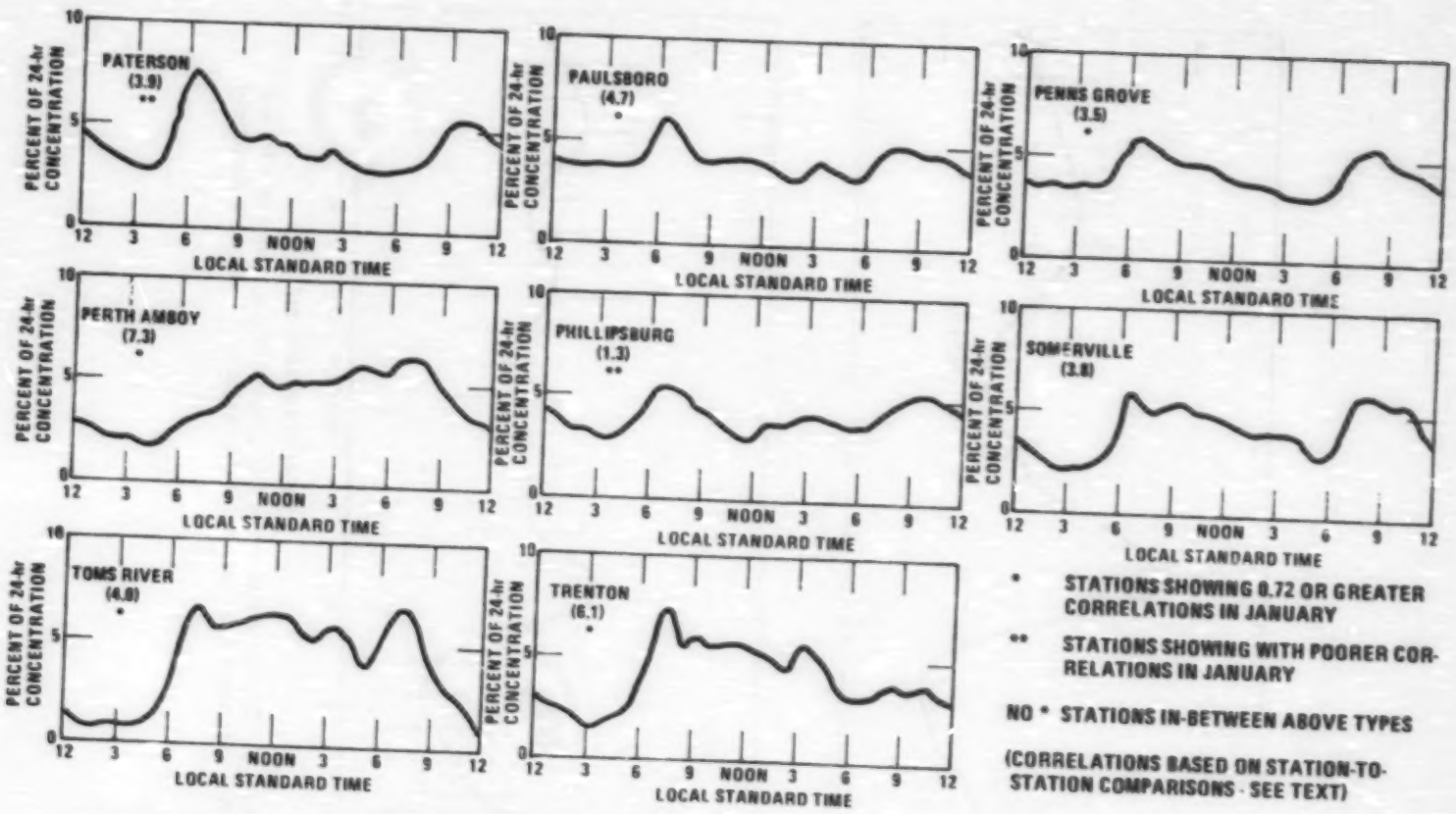

Figure 9 (continued). Diurnal variations in CO concentrations, New Jersey stations, July (numbers in parentheses are average hourly concentrations in ppm).

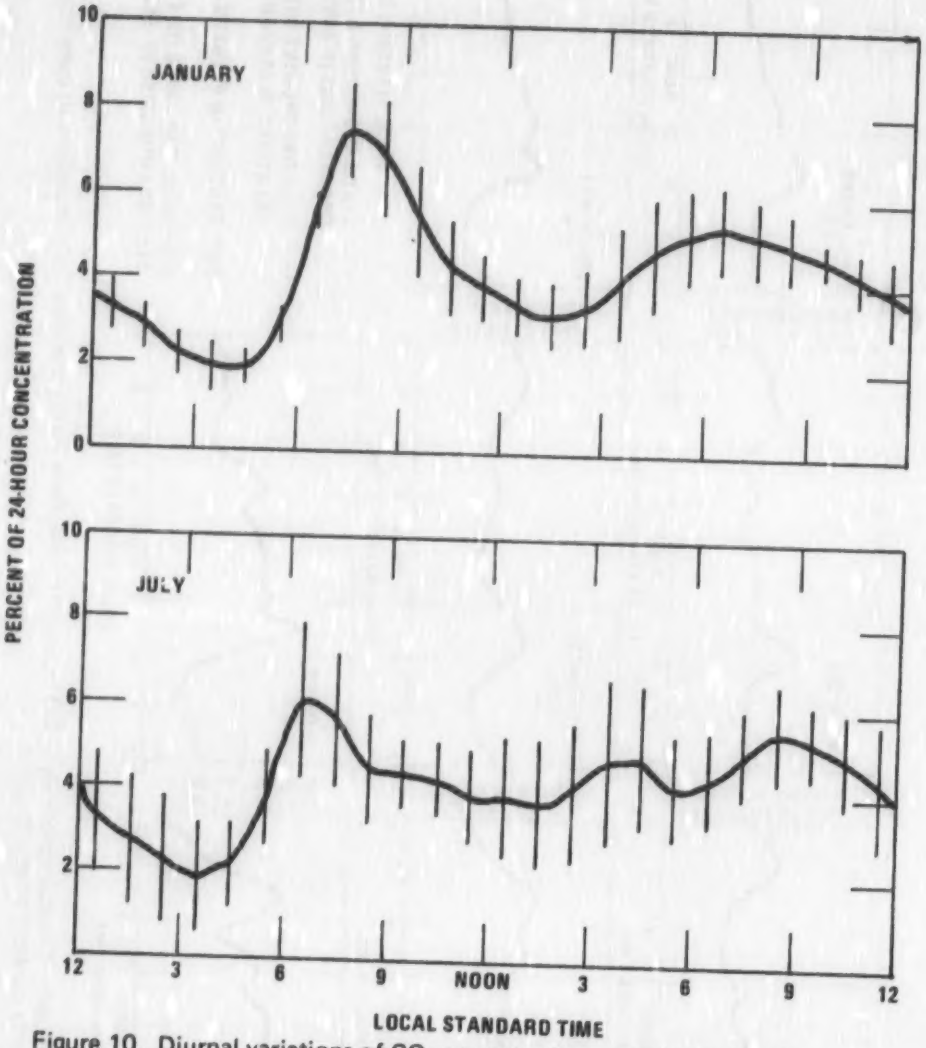

Figure 10. Diurnal variations of CO concentrations, composite for six Colorado stations (vertical lines show ranges of ± 1 standard deviation).

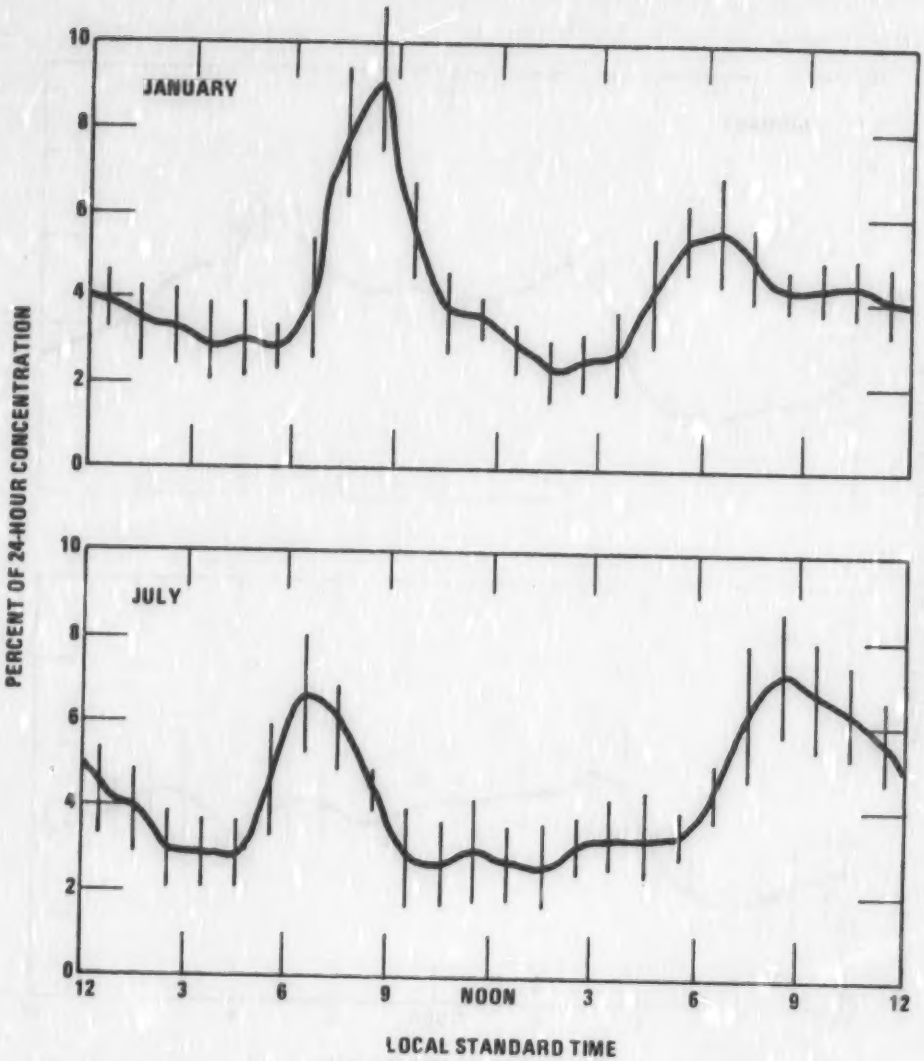

Figure 11. Diurnal variation of CO concentrations, composite for selected Maryland stations (vertical lines show ranges of ± 1 standard deviation).

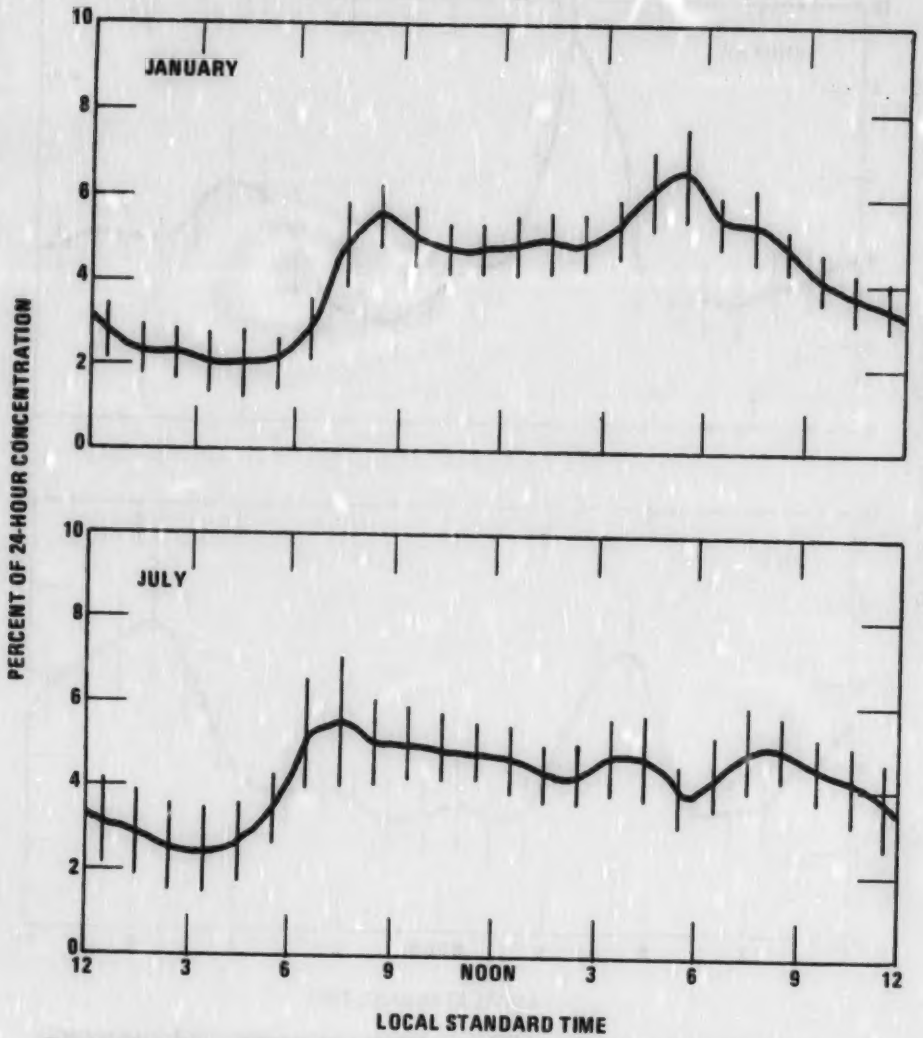

Figure 12. Diurnal variation of CO concentrations, composite for selected New Jersey stations (vertical lines show ranges of $\pm$ 1 standard deviation).

TABLE 1. TYPES AND LOCATIONS OF TRAFFIC COUNTING STATIONS

Station[a]	Type	Location
C 1	Urban	I-25 North of downtown Denver
C 8	Urban	US-36 Southeast of Broomfield (near Denver)
C 22	Urban	I-25 Valley Highway in Denver
C 23	Urban	First Avenue in downtown Denver
C 40	Urban	I-25 Freeway in Pueblo
C 7	Resort	I-70 East of Glenwood Springs (140 miles west of Denver)
C 39	Resort	US-34 East of Estes Park (60 miles NW of Denver)
M 25	Intercity highway[b]	Baltimore-Washington Expressway South of MD-176
M 39	Intercity highway[b]	I-95 North of MD-175
M 31	Urban beltway	I-695 West of Baltimore-Harrisburg Expressway
M 32	Urban beltway	I-695 South of U.S. 40
M 5	Small city highway	U.S. 301 South of Waldorf
M 23	Small city highway	MD-5 East of Waldorf
M 17	Ocean resort	U.S. 50 West of Ocean City
M 35	Mountain resort	U.S. 219 at McHenry
NJ 204	Truck route in city	U.S. 1T, Jersey City, between Duncan and Sip Avenues
NJ 208	Ocean resort	U.S. 30 Atlantic City, 0.5 mile East of Delilah Road
NJ 409	Small city roadway	South Collins Road, Camden, between Kearsarge and Tuckahoe Road

[a]Numbering system is that used by the respective states; C=Colorado, M=Maryland, NJ=New Jersey

[b]Between Baltimore and Washington

TABLE 2. DESCRIPTION OF CO MONITORING SITES

Station[a]	Area description	Intake Exposure	Nearby traffic[b]
Arvada (C)	Open field in a residential area 6 miles northwest of downtown area	(c)	60 feet to road carrying 3,500 vehicles
Broadway (C)	Small triangular plot in downtown area	17 feet above ground on side of building	21 feet to road carrying 1,700 vehicles and 30 feet to road carrying 7,500 vehicles
Julian (C)	Small parking lot near hospital 2 miles west of downtown area	(c)	36 feet to one road and 61 feet to another; each carries 1,000 vehicles
Colfax (C)	Field near hospital in center city commercial area	(c)	Many major intersections and roadways nearby
Huron (C)	Field 5 miles south of downtown area	(c)	Adjacent streets carry light traffic but nearby streets carry heavy traffic
Welby (C)	Open field in rural area 6 miles north northeast of downtown	(c)	42 feet to road carrying less than 1,000 vehicles
Baltimore (M) (Calvert St)	100-car parking field next to thoroughfare	(d)	90 feet to road carrying heavy afternoon traffic
Betnesda (M)	Meadow in metropolitan area	(d)	300 feet to road carrying about 100 vehicles
Cumberland (M)	Grassy field next to thoroughfare	(d)	20 feet to road carrying heavy morning traffic

TABLE 2. (continued).

Station[a]	Area description	Intake Exposure	Nearby traffic[b]
Gaithersburg (M)	Near thoroughfare in suburb	35 feet above ground, 18 in. from side of building	75 feet from road carrying 27,000 vehicles
Hyattsville (M)	Grassy field near the thoroughfare in metropolitan area	(d)	Below level of road and 75 feet from road carrying 30,000 vehicles
Linthicum (M)	Packed earth parking field at end of road	(d)	80 feet from road carrying about 100 vehicles and 600 feet from major thoroughfare
Riviera Beach (M)	Parking field next to little used side road	(d)	10 feet from road carrying 100 vehicles and 0.25 miles from thoroughfare
Silver Spring (M)	Park area next to thoroughfare	(d)	50 feet from 8-land thoroughfare carrying 90,000 vehicles
Suitland (M)	Edge of 500-car, asphalt covered parking field	(d)	150 feet from road carrying 18,500 vehicles
Towson (M)	Edge of woods	12 feet above ground atop building	Closest road, 500 feet away, carries 76,500 vehicles
Asbury (NJ)	City street	(e)	Road carries moderate to light traffic 3 blocks from ocean
Bayonne (NJ)	City park	(f)	Trailer is 0.75 miles from road with moderate traffic

TABLE 2. (continued).

Station[a]	Area description	Intake Exposure	Nearby traffic[b]
Burlington (NJ)	City street	(e)	Road is a main street but carries only moderate to light traffic
Camden 1 (NJ) (N. 6th st.)	City street	(e)	Downtown road which carries light traffic
Camden 2 (NJ) (Copewood & Davis)	Open field at medical research center	(f)	A block from light traffic; 3 blocks from heavy traffic
Camden 3 (NJ) (Ancora)	Rural state hospital 20 miles southeast of Camden	About 30 feet above ground 3 feet from side of building	No nearby traffic; heavily travelled 2 and 3 miles away
Elizabeth 1 (NJ) (Broad St.)	Center city street	(e)	Road carries heavy traffic
Elizabeth 2 (NJ) (N.J. Turnpike)	Turnpike interchange	(f)	Trailer is about 150 feet from exit-entrance area
Freehold (NJ)	Center city street	(e)	Street carries moderate to light traffic
Hackensack (NJ)	City street	(e)	Sampler is about 50 feet from light traffic and 400 feet from heavy traffic
Jersey City (NJ)	Street near city center	(e)	Street carries very heavy traffic

TABLE 2. (continued).

Station[a]	Area description	Intake Exposure	Nearby traffic[b]
Newark (NJ)	Corner of two streets	(f)	Each street is a one-way street; each carries heavy traffic
Paterson (NJ)	City street	(e)	Street carries light traffic; large amount of heavy-duty, gasoline-burning equipment used in nearby city dump
Paulsboro (NJ)	Center city street	(e)	Street carries light traffic
Penns Grove (NJ)	Center city street	(e)	Street carries light traffic
Perth Amboy (NJ)	Center city street	(e)	Street carries very heavy traffic
Phillipsburg (NJ)	Near corner of two streets	(e)	Sampler is 20 feet above sidewalk; street 20 feet away carries light traffic street 50 feet away carries heavy traffic
Somerville (NJ)	Center city street	(e)	Street carries moderate traffic
Toms River (NJ)	Near corner on main street	(e)	Street carries heavy traffic typical of area with a small population
Trenton (NJ)	Center city street	(e)	Street is now a mall; traffic was heavy

TABLE 2. (continued).

[a]All Colorado (C) stations are in Denver area; (M)=Maryland; (NJ)=New Jersey

[b]Vehicle counts are in counts per day; estimate of NJ traffic based on observation

[c]Exposure is 15 feet above ground atop trailer

[d]Exposure is 10 feet above ground atop trailer

[e]Exposure is 3 feet from side of building (projecting out from window) about 10-12 feet above ground

[f]Exposure is 12 feet above ground atop trailer

TABLE 3. CORRELATIONS OF LESS THAN 0.90 IN DIURNAL VARIATIONS IN TRAFFIC FOR JANUARY, 18 STATIONS[a]

	C 1	M 8	C 22	C 23	C 40	C 7	C 39	M 25	M 39	M 31	M 32	M 5	M 23	M 17	M 35	NJ 204	NJ 208	NJ 409
C7	-	0.89	0.85	-	-	-	-	-	-	0.87	0.88	-	-	-	-	-	0.84	0.82
C39	-	0.88	0.87	-	-	-	-	-	-	0.89	0.89	-	-	-	-	-	-	0.78
M17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.79
M35	-	0.89	0.87	-	-	-	-	-	-	-	-	-	-	-	-	-	0.86	0.81
NJ204	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.83	0.84
NJ208	0.87	0.88	-	-	-	0.84	-	-	-	-	0.89	0.89	0.89	-	0.86	0.88	-	0.89
NJ409	0.82	0.83	0.80	0.84	0.84	0.82	0.78	0.83	0.81	0.81	0.83	0.83	0.81	0.79	0.81	0.84	0.89	-

[a]All pairs not shown or marked by "-" were 0.90 or more.

C=Colorado, M=Maryland, NJ=New Jersey

TABLE 4. CORRELATIONS OF LESS THAN 0.90 IN DIURNAL VARIATIONS IN TRAFFIC FOR JULY, 18 STATIONS[a]

	C 1	C 8	C 22	C 23	C 40	C 7	C 39	M 25	M 39	M 31	M 32	M 5	M 23	M 17	M 35	NJ 204	NJ 208	NJ 409
C7	-	0.86	0.83	-	-	-	-	0.85	0.89	0.81	0.80	-	-	-	-	-	-	0.83
C39	-	0.88	0.85	-	-	-	-	0.87	-	0.83	0.82	-	-	-	-	-	-	0.82
M17	-	0.87	0.83	-	-	-	-	0.87	-	0.85	0.84	-	-	-	-	-	-	-
M35	0.86	0.80	0.76	0.86	-	-	-	0.83	0.82	0.77	0.79	-	-	-	-	-	-	-
NJ409	0.89	0.87	0.84	0.89	-	0.83	0.82	0.89	0.86	0.87	0.89	-	-	-	-	-	-	-

[a]All pairs not shown or marked by "-" were 0.90 or more.

C=Colorado, M=Maryland, NJ=New Jersey

TABLE 5. CORRELATION BETWEEN JANUARY AND JULY DIURNAL VARIATIONS IN TRAFFIC AT INDIVIDUAL STATIONS[a]

Station	Correlation	Station	Correlation
C1	0.99	M31	0.98
C8	0.99	M32	0.97
C22	0.99	M5	0.97
C23	0.99	M23	0.95
C40	0.98	M17	0.87
C7	0.98	M35	0.93
C39	0.95	NJ204	0.98
M25	0.98	NJ208	0.92
M39	0.99	NJ409	0.91

[a]C=Colorado, M=Maryland, NJ=New Jersey

TABLE 6. BIVARIATE CORRELATIONS OF DIURNAL VARIATIONS IN CO CONCENTRATIONS AT COLORADO STATIONS, JANUARY

	Arvada	Broadway	Julian	Colfax	Huron
Welby	0.88	0.51	0.77	0.46	0.46
Huron	0.71	0.66	0.84	0.83	
Colfax	0.75	0.90	0.66		
Julian	0.85	0.61			
Broadway	0.77				

TABLE 7. BIVARIATE CORRELATIONS OF DIURNAL VARIATIONS IN CO CONCENTRATIONS, COLORADO STATIONS, JULY.

	Arvada	Broadway	Julian	Colfax	Huron
Welby	0.23	0.58	0.75	-0.02	-0.03
Huron	0.84	0.51	-0.19	0.92	
Colfax	0.80	0.48	-0.21		
Julian	-0.07	0.04			
Broadway	0.67				

TABLE 8. BIVARIATE CORRELATIONS OF DIURNAL VARIATIONS IN CO CONCENTRATIONS, MARYLAND STATIONS, JANUARY

	Linth-icum	Balti-more	Bethesda	Cumber-land	Gaithers-burg	Hyatts-ville	Riviera Beach	Silver Spring	Suit-land
Towson	0.79	0.84	0.71	0.59	0.70	0.84	0.03	0.87	0.60
Suitland	0.78	0.62	0.70	0.81	0.89	0.46	0.20	0.77	
Silver Spring	0.92	0.81	0.90	0.81	0.85	0.84	0.25		
Riviera Beach	0.08	-0.04	0.31	0.38	0.33	0.16			
Hyattsville	0.77	0.81	0.78	0.56	0.60				
Gaithersburg	0.88	0.63	0.84	0.92					
Cumberland	0.88	0.63	0.81						
Bethesda	0.88	0.66							
Baltimore	0.80								

TABLE 9. BIVARIATE CORRELATIONS OF DIURNAL VARIATIONS IN CO CONCENTRATIONS, MARYLAND STATIONS, JULY

	Linth-icum	Balti-more	Bethesda	Cumber-land	Gaithers-burg	Hyatts-ville	Riviera Beach	Silver Spring	Suit-land
Towson	0.64	0.76	0.86	0.77	0.78	0.84	-0.19	0.69	0.75
Suitland	0.89	0.77	0.69	0.84	0.78	0.81	-0.32	0.69	
Silver Spring	0.45	0.91	0.74	0.83	0.77	0.66	0.09		
Riviera Beach	-0.36	-0.02	-0.24	-0.02	0.13	-0.44			
Hyattsville	0.77	0.75	0.85	0.71	0.61				
Gaithersburg	0.66	0.70	0.75	0.87					
Cumberland	0.69	0.84	0.72						
Bethesda	0.65	0.71							
Baltimore	0.54								

TABLE 9. BIVARIATE CORRELATIONS OF DIURNAL VARIATIONS IN CO CONCENTRATIONS, MARYLAND STATIONS, JULY

	Linth-icum	Balti-more	Bethesda	Cumber-land	Gaithers-burg	Hyatts-ville	Riviera Beach	Silver Spring	Suit-land
Towson	0.64	0.76	0.86	0.77	0.78	0.84	-0.19	0.69	0.75
Suitland	0.89	0.77	0.69	0.84	0.78	0.81	-0.32	0.69	
Silver Spring	0.45	0.91	0.74	0.83	0.77	0.66	0.09		
Riviera Beach	-0.36	-0.02	-0.24	-0.02	0.13	-0.44			
Hyattsville	0.77	0.75	0.85	0.71	0.61				
Gaithersburg	0.66	0.70	0.75	0.87					
Cumberland	0.69	0.84	0.72						
Bethesda	0.65	0.71							
Baltimore	0.54								

TABLE 10. BIVARIATE CORRELATIONS OF DIURNAL VARIATIONS IN CO CONCENTRATIONS AT 13 SELECTED NEW JERSEY STATIONS, JANUARY.

	Asbury	Burl-ington	Camden 2	Eliza-beth 1	Free-hold	Hack-ensack	Jersey City	Newark	Pauls-boro	Penns Grove	Perth Amboy	Toms River
Trenton	0.88	0.94	0.88	0.93	0.85	0.80	0.83	0.87	0.72	0.95	0.96	0.93
Toms River	0.90	0.90	0.85	0.93	0.87	0.77	0.90	0.89	0.80	0.97	0.93	
Perth Amboy	0.90	0.94	0.82	0.92	0.84	0.84	0.84	0.87	0.73	0.94		
Penns Grove	0.93	0.94	0.87	0.97	0.92	0.82	0.91	0.91	0.83			
Paulsboro	0.91	0.82	0.78	0.88	0.91	0.88	0.89	0.87				
Newark	0.95	0.86	0.87	0.91	0.85	0.82	0.95					
Jersey City	0.93	0.85	0.83	0.92	0.89	0.83						
Hackensack	0.93	0.88	0.80	0.90	0.89							
Freehold	0.93	0.95	0.88	0.97								
Elizabeth 1	0.95	0.96	0.90									
Camden 2	0.89	0.91										
Burlington	0.92											

TABLE 11. BIVARIATE CORRELATIONS OF DIURNAL VARIATIONS IN CO CONCENTRATIONS AT FIVE SELECTED NEW JERSEY STATIONS, JANUARY

	Asbury	Bay-onne	Burl-ington	Camden 1	Camden 2	Camden 3	Eliza-beth 1	Eliza-beth 2	Free-hold	Hack-ensack	Jersey City	Newark
Bayonne	0.32		0.48	0.27	0.37	0.25	0.36	0.13	0.37	0.32	0.08	0.14
Camden 1	0.69	0.27	0.67		0.59	0.56	0.68	0.87	0.76	0.83	0.55	0.53
Elizabeth 2	0.78	0.13	0.69	0.87	0.65	0.51	0.74		0.81	0.87	0.73	0.69
Paterson	0.29	-0.21	0.28	0.45	0.20	0.32	0.33	0.62	0.48	0.37	0.38	0.28
Phillipsburg	0.72	0.23	0.66	0.83	0.57	0.49	0.70	0.93	0.76	0.82	0.64	0.63

Table 12. Bivariate Correlations of Diurnal Variations in CO Concentrations at 13 Selected Stations, July.

	Asbury	Burl-ington	Camden 2	Eliza-beth 1	Free-hold	Hack-ensack	Jersey City	Newark	Pauls-boro	Penns Grove	Perth Amboy	Toms River
Trenton	0.85	0.73	0.93	0.67	0.90	0.22	0.48	0.67	0.19	0.24	0.49	0.83
Toms River	0.90	0.55	0.74	0.78	0.81	-0.05	0.68	0.65	0.18	0.33	0.83	
Perth Amboy	0.80	0.18	0.42	0.67	0.44	-0.25	0.82	0.59	-0.03	0.09		
Penns Grove	0.29	0.72	0.28	0.60	0.43	0.44	0.17	0.29	0.85			
Paulsboro	0.19	0.64	0.26	0.60	0.34	0.52	0.25	0.41				
Newark	0.72	0.52	0.74	0.90	0.62	0.22	0.86					
Jersey City	0.70	0.27	0.54	0.83	0.46	-0.07						
Hackensack	0.23	0.63	0.29	0.26	0.06							
Freehold	0.73	0.76	0.89	0.69								
Elizabeth 1	0.79	0.68	0.71									
Camden 2	0.80	0.78										
Burlington	0.65											

Table 13. Bivariate Correlations of Diurnal Variations in CO Concentrations at 6 Selected New Jersey Stations, July.

	Asbury	Bay-onne	Burl-ington	Camden 1	Camden 2	Camden 3	Eliza-beth 1	Eliza-beth 2	Free-hold	Hack-ensack	Jersey City	Newark
Bayonne	0.29		0.27	0.77	-0.12	-0.72	0.18	0.66	-0.06	0.29	-0.05	-0.04
Camden 1	0.36	0.77	0.10		-0.25	-0.64	0.13	0.70	-0.33	0.47	0.01	0.10
Elizabeth 2	0.12	0.66	0.35	0.70	0.29	-0.44	0.64		0.21	0.27	0.54	0.62
Paterson	0.36	0.52	0.60	0.65	0.44	-0.29	0.74	0.82	0.30	0.61	0.48	0.66
Phillipsburg	0.75	0.20	0.81	0.15	0.61	0.24	0.84	0.41	0.58	0.55	0.52	0.65
Camden 3	0.52	-0.72	-0.09	-0.64	0.15	1.00	0.19	-0.44	0.18	-0.33	0.35	0.23

Table 14. Correlations of January and July Diurnal Variations of CO Concentrations

Station	Correlation	Station	Correlation	Station	Correlation
Linthicum	0.15	Julian	0.58	Freehold	0.90
Baltimore	0.35	Colfax	0.80	Hackensack	0.80
Bethesda	0.28	Huron	0.57	Jersey City	0.79
Cumberland	0.39	Welby	0.70	Newark	0.82
Gaithersburg	0.34	Asbury	0.79	Paterson	0.65
Hyattsville	0.24	Bayonne	-0.26	Paulsboro	0.67
Riviera Beach	0.61	Burlington	0.39	Penns Grove	0.87
Silver Spring	0.44	Camden 1	-0.08	Perth Amboy	0.94
Suitland	0.24	Camden 2	0.55	Phillipsburg	0.78
Towson	0.38	Camden 3	0.47	Somerville	0.66
Arvada	0.55	Elizabeth 1	0.65	Toms River	0.90
Broadway	0.86	Elizabeth 2	0.68	Trenton	0.90

Table 15. Correlations of Diurnal Variations, January and July.

Basic traffic patterns verses statewide CO patterns		Interstate CO correlations	
January		**January**	
Traffic: Colorado CO	0.52	Colorado CO: Maryland CO	0.85
Traffic: Maryland CO	0.25	Colorado CO: New Jersey CO	0.64
Traffic: New Jersey CO	0.94	Maryland CO: New Jersey CO	0.42
July		**July**	
Traffic: Colorado CO	0.58	Colorado CO: Maryland CO	0.56
Traffic: Maryland CO	-0.19	Colorado CO: New Jersey CO	0.87
Traffic: New Jersey CO	0.79	Maryland CO: New Jersey CO	0.31